APPENDIX M

TERRESTRIAL HABITAT PREFERENCES OF ADULT ARROYO SOUTHWESTERN TOADS

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TERRESTRIAL HABITAT PREFERENCES OF ADULT ARROYO SOUTHWESTERN TOADS

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Abstract: Using an external belt attachment system, we attached 1.8-g radiotransmitters to arroyo southwestern toads (*Bufo microscaphus californicus*). We tracked 83 arroyo southwestern toads over an average period of 30.9 days (SD = 29.0) in 1998. Male calling activity began at the study site on 6 March and ended on 29 July. We observed arroyo toad activity in upland habitats throughout the study. We examined the habitat preferences of arroyo toads by comparing land cover within a minimum convex polygon estimate home range for each animal to the study site subarea where each toad occurred. We also compared substrate, vegetation, and vegetation structure use to availability within each minimum convex polygon area. We found significant between-sex differences in land use and vegetation-type preferences during the study, but not for substrate or vegetation-structure preferences. Female arroyo southwestern toads preferred terrace and channel habitats to campground, agricultural, or upland habitats. During the breeding season, male arroyo southwestern toad preference for channel habitats was significantly greater than for all other habitat types. Toads preferred sands for burrowing substrate, but no substrate type was preferred for surface activity. Differences in preference rank for vegetation type were weak. Male use of agricultural lands adjacent to breeding sites increased after the breeding season. Dense, tall vegetation structures were least preferred by arroyo southwestern toads for burrows. Arroyo southwestern toads may forage and disperse through many vegetation types that are common in riparian and upland habitats of southern California.

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In light of the recent and widespread decline of amphibians (Blaustein and Wake 1990; Pechmann et al. 1991; Wake 1991, 1998; Pechmann and Wilbur 1994), identifying and protecting habitats that are used by endangered amphibians has acquired special significance. For long-term conservation, wildlife managers should increase efforts to conserve the natural disturbance regimes and successional dynamics that promote the continuous availability of preferred breeding and terrestrial habitats. Preferred terrestrial habitats have not been identified for many endangered amphibians because observations have been limited to aquatic breeding sites, where frogs and salamanders can be seasonally abundant and conspicuous.

The arroyo southwestern toad (hereafter arroyo toad) is a federally endangered (Federal Register 1994) amphibian species (Gergus 1998) of southern and central California, USA, and northern Baja California, Mexico. Extant arroyo toad populations are principally found in the coastal plain and mountains near rivers and adjacent uplands (Patten and Myers 1992, Jennings and Hayes 1994). The arroyo toad was formerly widespread, but many populations are extirpated, and currently only 22 river systems remain that contain populations of the arroyo toad. Most observations of arroyo toads are associated with sandy 3rd to 6th order (Strahler 1952, Gordon et al. 1992) floodplains within 0.5 km of seasonal river breeding sites (Federal Register 2001). The highly dynamic river and riparian habitats of southern California where arroyo toads reproduce support many other threatened and endangered species, including southwestern willow flycatcher (*Empidonax trailii extimus*), least Bell's vireo (*Vireo belli pusillus*), tidewater goby (*Eucyclogobius newberryi*), and steelhead trout (*Oncorhynchus mykiss*).

Arroyo toad populations persist in an environment of floods and fires that change both upland foraging habitats and the structure of aquatic habitats vital for breeding and larval development (U.S. Fish and Wildlife Service 1999). Natural floodplains are heterogeneous landscapes with patches of various landforms, sediment deposits, and vegetation age and type. The creation of reservoirs, lowering of water tables from irrigation, paving, sediment mining, and the introduction of exotic flora and fauna are conspicuous human actions that have negatively

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impacted arroyo toad habitats. Habitat fragmentation in aquatic habitats and their watersheds can lead to population declines in patches that remain (Sheldon 1988, Dodd 1990, Bradford et al. 1993, Page et al. 1997). Exotic fishes and amphibians may eat arroyo toad larvae, juveniles (U.S. Fish and Wildlife Service 1999), and adults (Griffin and Case, unpublished data). Exotic plants such as giant reed (*Arundo donax*) can grow densely in floodplains where arroyo toads live, altering vegetative habitats and stream hydrology (U.S. Fish and Wildlife Service 1999).

Arroyo toad eggs are externally fertilized in water and develop into embryos that hatch as larvae. Larvae develop and metamorphose into terrestrial toads. Arroyo toads breed in sandy pools in rivers with intermittent, seasonal flow, with a breeding period that may range from late February through July, depending on elevation and latitude. Breeding at a given site may extend over several months (Cunningham 1961). Small terrestrial toadlets can burrow into loose soils within days after metamorphosis. Males may reach sexual maturity 1 year after metamorphosis, although they do not generally reach full male adult size until age 2. Females require 2 years to reach sexual maturity (S. Sweet, University of California at Santa Barbara, unpublished data).

Except during the breeding period, most bufonids are essentially terrestrial (Beebee 1985). Elevated terraces close to breeding streams are important habitats for burrowed and active arroyo toads, both during and after the breeding season (U.S. Fish and Wildlife Service 1999). Adult arroyo toads have been found hundreds of meters from watercourses (Cunningham 1961), and over 1 km from water in low-elevation populations (D. Holland, Camp Pendleton Amphibian and Reptile Survey, unpublished data). Welsh (1988:20) also noted arroyo toads in Baja California "... far from water, in coastal sage scrub and chaparral." Burrowing is a common behavior in many bufonids living in arid to semi-arid regions (Warburg 1997). Toads in burrows may experience less daily fluctuation in temperature and may have more moisture available to absorb than they would if they were at the surface (Cunningham 1961), and are hidden from potential predators. Substrates suitable for burrowing, therefore, must be available in areas used throughout the year.

Adult survival may depend on the availability of adequate terrestrial habitats. It is, therefore, important to identify those substrates, vegetation types, and vegetation structures that are preferred by arroyo toads for burrowing and surface activity. Absolute measures of preference can only be measured experimentally, but relative affinity for 1 habitat over another can be measured by comparing the relative use and availability of habitats (Garshelis 2000). Despite this distinction, we will use the term preference to mean simply affinity.

Comparisons of used to available habitats are tools for identification of habitat features that are used in greater proportion than their availability (Johnson 1980, Thomas and Taylor 1990). The principle goal of this analytical technique is to identify habitat features that are used in a greater proportion than expected, based on their availability to the animal. Two spatial scales of habitat preference can be studied using radiotelemetry data from individuals (Aebischer et al. 1993). Second-order selection is the selection of a home range or its proxy within a landscape (Johnson 1980). Use at this level does not imply that every point within the home range is used; at this scale, the habitats within a home range or its proxy are compared to the available habitats within the entire study area. Assessing third-order selection involves comparing microhabitats observed as used by individuals to those available to each individual (Johnson 1980). In radiotracking studies, it is possible to limit the definition of available microhabitats to those within each individual's home range or its proxy (Thomas and Taylor 1990, Aebischer et al. 1993). These methods may not identify all microhabitats that are important for study animals; any use versus availability analysis will underestimate the importance of habitat features that are only rarely used, but widely available (Garshelis 2000).

Our objective was to identify the habitat features that adult arroyo toads rely on for their nonbreeding behaviors. Recently available miniature radiotransmitters allowed us to follow individuals and to find the burrows where they spent the day. We hypothesized that certain substrate, vegetation, or structural habitat features must be important if we find arroyo toads using them repeatedly, and more than other available habitat features (Johnson 1980). Studies using radiotracked individuals as sample units to assess preference have the greatest power to detect habitat preferences at multiple scales (Thomas and Taylor 1990, Aebischer et al. 1993). We used compositional analysis to examine habitat preferences because this method is robust to problems

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STUDY AREA

We conducted all radiotracking studies in the San Mateo River watershed on U.S. Marine Corps Base (USMCB) Camp Pendleton, California (Fig. 1). This coastal watershed occupies approximately 235 km^2. The arroyo toad population at this area is relatively large compared to other extant populations, as is the extent of riparian habitat in the watershed (U.S. Fish and Wildlife Service 1999). The timing of river flow in the San Mateo River watershed usually lasts from late winter through spring and is probably typical of the historic condition for free-flowing medium-sized coastal rivers of southern California.

Our study site included 3 subareas. The lower San Mateo subarea is a 5th order river that drains to the ocean. At high water levels it can occupy 3 or more channels. Adjacent uplands are predominantly native coastal sage scrub, agricultural fields, or semi-paved campground. The Cristianitos Creek subarea is a 4th order tributary with a wide, sandy floodplain where the creek flows in several channels during floods. Sycamores, oaks, and scrub vegetation are most dense near a permanent spring and on an elevated terrace. California's Department of Transportation is considering the construction of an 8-lane freeway through these first 2 subareas. The third subarea, Talega Creek, is a 3rd order tributary of Cristianitos Creek. A narrow band of riparian vegetation lies next to Talega Creek, but the canyon is narrower and steeper than the other subareas. Hillsides in Talega Canyon are vegetated mostly in chaparral, coastal sage scrub, and nonnative grasses. Arroyo toad densities appear to differ in these subareas, with the greatest numbers found in the Lower San Mateo subarea.

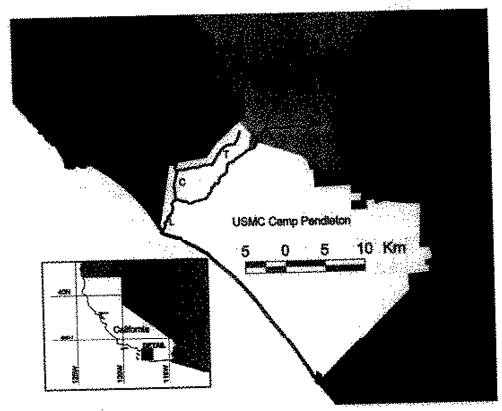

Fig. 1. The position of the San Mateo River study site in California showing latitude and longitude. The San Mateo River and its tributaries are shown as lines in the expanded map. Single letters indicate the lower San Mateo (L), Cristianitos (C) and Talega (T) study site subareas. Most of the coastal watershed is within U.S. Marine Corps Camp Pendleton (white) and the U.S. Forest Service San Mateo wilderness (light grey).

METHODS

Radiotracking and Arroyo Toads

We captured arroyo toads in pitfall traps (Fisher and Case 2000), and at night along the stream edge. Following suggestions in Richards et al. (1994), we attached cryptically colored, 1.8-g radiotransmitters (Holohil Ltd., Carp, Canada and Sirtrack Ltd., Havelock North, New Zealand) using the belt design (Bartelt and Peterson 2000) and 1.5-mm tubing (Fig. 2). Sizing each belt to match individual toads was critical, because an arroyo toad could easily pull its hind legs from a belt that was too loose, and a belt that was too tight could constrain the animal. We removed belts from animals that showed any sign of abrasion.

From February to September 1998, we used a handheld antenna and receiver (AVM Instruments, Livermore, California, USA) to locate toads

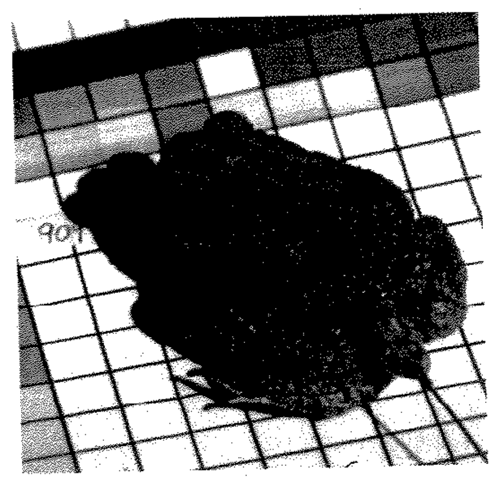

Fig. 2. Female arroyo southwestern toad. 60 mm snout-urostyle (body) length. A 1.8-g radiotransmitter was attached to the toad with a 1.5-mm diameter tubing belt. Grid squares are 1 cm.

with transmitters. Only data from these locations were used in all subsequent analyses. Most toad locations were made during daylight hours when toads were generally in burrows although some observations were made at night. If a toad was above ground at the time of location, it was considered active. If a toad's belt was located above ground at a point where the animal had escaped from the belt, then that was also considered an active location. We attempted to find each toad at least once every 3 days. Initially, we monitored the physical condition of each toad every 2 weeks. After we found some toads with chafed skin we decreased monitoring intervals to once per week.

We recorded exact locations of burrowed or active radiomarked arroyo toads with Global Positioning System (GPS; Trimble GeoExplorer, Sunnyvale, California, USA), and differentially post-processed to an accuracy of ±2 m. We recorded locations for each individual in a Geographic Information System (GIS; ArcView, ESRI, Redlands, California, USA) that we used to compile all spatial data. We plotted location data to delimit minimum convex polygons (MCP; Mohr and Stumpf 1966, Jennrich and Turner 1969); these are areas enclosing habitats that were accessible and, therefore, could have been used by each arroyo toad. At least 3 locations delimiting the outside of a polygon are necessary to delimit a MCP for an individual. The designation of these habitats as potentially available is conservative, because no further information about the range of nightly movement distances is available. Although habitats within a MCP area were available to an animal, the MCP area should not be considered that animal's annual or lifetime home range.

Analysis of Habitat Preference

We used high-resolution digital photographs (USMCB Camp Pendleton) and our experience in the study site to classify land-cover type polygons. The land-cover types that we designated were (1) agricultural (including dirt roads), (2) campground, (3) channel, (4) terrace, and (5) upland. Terraces showed evidence of rare scouring from extreme flood events. Uplands were not prone to flooding. The proportion of each land-cover type was estimated within each arroyo toad's observed MCP area, using GIS. We considered those as the proportions used by each individual. We estimated the available proportions of land-cover types available within each study site subarea.

We analyzed the preferences of arroyo toads for substrate, vegetation, and vegetation structure types, relative to the available proportions of those habitat types in each toad's MCP area. Microhabitat attributes were recorded where we observed arroyo toads and in systematic samples of each study site subarea. We used the number of times each animal was found burrowed or active in each microhabitat to obtain the used data and converted these values to proportions. We documented the availability of the same microhabitat attributes along systematic transects. Each transect was 40 m wide and 40 to 400 m long, with a lattice of sampled points spaced at 10-m intervals. These sample points were mapped in GIS, based on GPS reference points at 50-m intervals. We used GIS to tally the number of observations of each microhabitat type within each toad's MCP area and converted these values to proportions. All 3 subareas, despite their different sizes and numbers of toads with radiotransmitters, received approximately the same proportion of sampled area in systematic surveys of microhabitats.

Microhabitat selection by burrowed arroyo toads was based on combined active and burrow locations that defined a MCP area. At least 10 or more sample points of available microhabitat features within the MCP-utilized area ($n = 33$) were measured. Our analyses of surface activity habitat preferences were limited to arroyo toads for which we had adequately sampled available habitats in a MCP area and for which we had observed at the surface or found the locations where they escaped from their radiotransmitter ($n = 21$).

We classified substrates into size categories that we regularly encountered as well-sorted classes during pilot work at the study site: clay, silt, fine sand, medium sand, coarse sand, gravel, and cobble. We estimated substrate crust depth to the nearest centimeter. Vegetation classes were grouped according to general physiognomic category, with reference to the tallest vegetation type directly over the sampled point. Vegetation structure was recorded at each sampled point as total canopy cover over the ground, and the percentage of that vegetative cover coming from 4 height layers: 0 to 5 cm, 5 to 50 cm, 50 to 200 cm, and over 200 cm. After collection of field data, we examined the distribution of total canopy cover for natural breaks and defined 7 categories of vegetation structure (Table 1): (1) no vegetation; (2) sparse–low (20% or less total cover, all from vegetation 50 cm or lower); (3) sparse–tall (20% or less total cover, 25% or more of which is from vegetation over 50 cm high); (4) medi-

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Table 1. Vegetation structure types designated in this study. The 6 hyphenated categories are based on estimated canopy coverage over a sampled point (row) and on distribution by height (column).

Canopy category	Low[a]	Tall[b]
1–20% canopy	sparse–low	sparse–tall
25–75% canopy	medium–low	medium–tall
80–100% canopy	dense–low	dense–tall

[a] 75% or more of total vegetation structure is lower than 50 cm.
[b] 25–75% of vegetation structure is taller than 50 cm.

um–low (25% to 75% total cover, all from vegetation 50 cm or lower); (5) medium–tall (25% to 75% total cover, 25% or more of which is from vegetation over 50 cm high); (6) dense–low (over 80% total cover, all from vegetation 50 cm or lower); (7) and dense–tall (over 80% total cover, 25% or more of which is from vegetation over 50 cm high). The number of available sample points in each vegetation structure type and vegetation type is listed in Table 2.

Compositional Analysis

We used compositional analysis to compare the ratios of used to available habitat because this method accounts for the fact that the proportions of used and available habitats add to 1 (Aitchison 1986, Aebischer et al. 1993). Recently, this method has been applied in conservation and management studies (Tufto et al. 1996, Saunders et al. 1997, Tella et al. 1998, Genovesi et al. 1999, Miller et al. 1999, Linnell et al. 1999). Compositional analysis of tracking data uses all the data from 1 animal as 1 replicate, and makes use of log-ratio transformation before testing the hypothesis that the observed matrix of [(log-ratio used) – (log-ratio available)] values is statistically nonrandom (Aebischer et al. 1993). The analysis then summarizes the pairwise comparisons of these ratios between all habitat types and determines whether the mean differences, d, in (used:available) ratios for pairs of habitat types are significant across all animals. The results of compositional analysis are a ranked list of habitat preference and a statistical test of significance between ranks (Aebischer et al. 1993). If preference for large number of animals is detected despite a low number of relocations per animal, then this may indicate a strong preference.

We used MANOVA on the matrix of log-ratio (used – available) data for each of the 4 analysis categories to determine whether data for males and females could be pooled for each analysis. We used software (F. Leban, University of Idaho, personal communication) to perform compositional analysis of burrowed arroyo toad preference for land cover, substrate, vegetation type, and vegetation structure habitats. We also performed compositional analysis of active arroyo toad preference for substrate, vegetation, and vegetation structure microhabitats. Nominal significance level for all statistical tests was at the $\alpha = 0.05$ level.

RESULTS

There was abundant spring rain during 1998, due to El Niño. As a result, there was river flow through the early summer at all subareas. Based on the detectable presence of calling males, the breeding

Table 2. Vegetation and habitat structure types recorded in the study of arroyo southwestern toads during 1998. Vegetation types show the percentage of systematically sampled available points in each study site subarea and the total number of points sampled. Habitat structure types show the percentage of available points in each study site subarea and the total number of points sampled. Study subareas on U.S. Marine Corps Base Camp Pendleton, California, USA, are Lower San Mateo River (LSM), Talega Creek (TC), and Cristianitos Creek (CC).

	Subarea		
Habitat type	LSM	TC	CC
Vegetation type			
None	60.8	22.8	32.4
Debris pile	2.3	1.5	4.3
Chaparral	0.6	3.4	1.4
Nonnative grasses	3.9	9.5	6.5
Coastal sage scrub	4.6	10.6	3.6
Willow and mulefat	19.0	8.6	36.0
Large exotics	7.0	0.1	10.8
Annuals	1.0	20.5	2.2
Sycamore	0.7	15.3	2.2
Oak	0.1	7.7	0.7
Total # of sampled points	1,147.0	821.0	139.0
Habitat structure type			
No vegetation	40.5	19.3	32.2
Dense–tall	12.6	23.4	3.4
Medium–low	10.2	12.0	14.4
Sparse–low	14.7	16.1	20.5
Dense–low	6.4	5.3	1.4
Medium–tall	13.3	14.9	19.9
Sparse–tall	2.4	2.6	4.1
Total # of sampled points	1,614.0	933.0	146.0

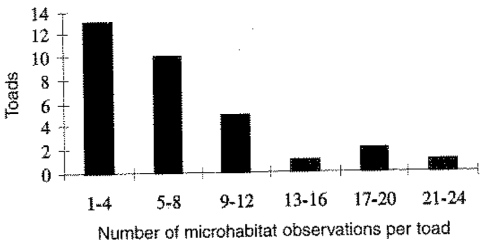

Fig. 3. Distribution of the number of burrow locations per animal for the 33 arroyo southwestern toads used in analyses of burrow site microhabitat preferences. Burrow locations were compared with available microhabitats within the minimum convex polygon of each toad to test for burrow microhabitat preferences.

season extended from 6 March to 29 July. Tracking began on 3 February and ended on 6 September. We infrequently observed active arroyo toads diurnally ($n = 6$); most directly observed surface activity was nocturnal ($n = 17$). Another 43 active locations were at points where we recovered the transmitter and belt from which a toad had escaped.

We tracked 83 arroyo toads over an average period of 30.9 days (SD = 29.0 days) at the lower San Mateo River subarea ($n = 63$), Cristianitos Creek subarea ($n = 4$), and Talega Creek subarea ($n = 16$). When animals that were tracked for fewer than 10 days were excluded from the analysis, no significant differences occurred in mean number of days that male ($n = 46$, mean = 39.5, SD = 27.9) and female ($n = 14$, mean = 47.1, SD = 27.1) animals were tracked ($t = 0.898$, df = 58, $P = 0.373$). We recorded enough data to compare used with available burrow microhabitats for 33 arroyo toads (Fig. 3).

Selection of General Land-Cover Types in MCP Areas Compared to Subareas

All analyses of habitat preference rejected the hypothesis that habitat types were used at random with respect to their availability (df = number of habitat types – 1; $P < 0.005$ in all analyses). Counting the land-cover types within study site subareas as available and MCP areas as used, significant differences occurred in the log-ratio (used – available) land-cover type vectors (agriculture, camping, terrace, channel, upland) for male ($n = 42$) and female ($n = 15$) arroyo toads (MANOVA; Wilks' $\lambda = 0.740$, $F_{4, 52} = 4.558$, $P < 0.005$), so data were not pooled. Male arroyo toads tended to make their burrows close to the waters of the river or creek where breeding could have taken place. During the breeding season the average distance from the river or creek where male arroyo toads made their burrows was 28.0 m (SE = 2.21). Female arroyo toads in the breeding season were found farther than males from the river or creek on average (mean = 72.2 m, SE = 23.8). During the breeding period, the mean maximum distance that individual females were observed away from breeding streams was 134.9 m (SD = 58.3); the mean maximum distance individual males were observed away from breeding streams was 73.1 m (SD = 74.8).

Female arroyo toads had MCP areas that included use of terrace and channel habitats significantly more than campground, agricultural, or upland habitats. The next most preferred habitats were upland and campground habitats, which were not significantly different from each other in preference, but which were significantly preferred compared to agricultural habitats (Table 3). Our methods could not have detected postbreeding female use of agricultural fields; many females escaped from the transmitter and belt during breeding activity and no females were tracked after 29 July.

During this study period, male arroyo toad preference for channel habitats was significantly greater than for all other habitat types. No significant difference was found in preference between agricultural and upland land cover types for males (Table 3).

Male use of riparian habitats decreased after the end of the breeding season, when we observed that males had moved into upland habitats. Only 4 of 43 males monitored during the breeding season were found in agricultural fields, but 4 of 7 males that were monitored after the breeding season burrowed in agricultural fields. Males were found in agricultural fields significantly more after the breeding period ($\chi^2 = 10.52$, $P < 0.005$; G-test of independence = 7.79, $P < 0.010$).

Selection of Burrowing Substrates

No significant differences occurred in the log-ratio (used – available) substrate type vectors for male ($n = 24$) and female ($n = 9$) arroyo toads (MANOVA; Wilks' $\lambda = 0.814$, $F_{5, 27} = 1.234$, $P = 0.321$), so data were pooled. Sands were significantly preferred for burrowing over all other substrates (Table 3). Medium, coarse, and fine sands were not significantly different in their relative preference. Arroyo toads did not show a difference in their low preference for clay–silt, gravel, and cobble substrates as burrowing sites.

Table 3. Relative ranks of arroy
highly preferred types are listed
tinguishable differences in prefe
significant ($P < 0.05$) difference
($0.05 < P < 0.10$). Microhabitat

Habitat	n
Land cover[a]	
Female	15
Male	42
Substrate[b]	
Both sexes	33
Vegetation[b]	
Female	9
Male	24
Vegetation structure[b]	
Both sexes	33

[a] Minimum convex polygon ar
study site subarea.
[b] Microhabitats of toad burrow
systematic samples throughout

Some arroyo toads sho
sites. Five arroyo toads re
location used previously, c
more than 100 m away fo

Most burrows used by a
the toads. We observed 12
burrows 1 or more times
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Selection of Vegetation Burrow Sites

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Table 3. Relative ranks of arroyo southwestern toad preference for habitat types at coarse and microhabitat scales. The most highly preferred types are listed at left, with decreasingly preferred types listed to the right. Habitat types that did not have distinguishable differences in preference are listed alphabetically within parentheses. Three greater than signs indicate statistically significant ($P < 0.05$) differences in preference between habitats, and a single greater than sign indicates a trend in preference ($0.05 < P < 0.10$). Microhabitat scale preference ranks reflect burrow locations only.

Habitat	n	Ranked list of habitat categories
Land cover[a]		
Female	15	(terrace, channel) >>> (campground, upland) >>> (agricultural)
Male	42	(channel) >>> (terrace) >>> (campground) >>> (agricultural, upland)
Substrate[b]		
Both sexes	33	(coarse sand, fine sand, medium sand) >>> (clay–silt, cobble, gravel)
Vegetation[b]		
Female	9	(coastal sage, debris, none, nonnative grass, oak, sycamore, willow and mulefat)
Male	24	(agriculture, coastal sage, oak) > (chaparral, debris, large exotics, none, nonnative grasses, sycamore, willow and mulefat) > (low annual plants)
Vegetation structure[b]		
Both sexes	33	(medium–tall, none, sparse–tall) > (dense–low, medium–low, sparse–low) >>> (dense–tall)

[a] Minimum convex polygon areas used by arroyo southwestern toads are compared with the available land-cover types in the study site subarea.

[b] Microhabitats of toad burrows are compared with microhabitats within each toad's minimum convex polygon, as recorded in systematic samples throughout the study site.

Some arroyo toads showed fidelity to burrow sites. Five arroyo toads returned to use a burrow location used previously, despite having burrowed more than 100 m away for periods over 14 days.

Most burrows used by arroyo toads were dug by the toads. We observed 12 arroyo toads that made burrows 1 or more times within the footprints of cows, deer, humans, and dogs, predominantly made in areas where the substrate had a 1 to 4 cm crust. The depth of crust at the surface near burrows made in the prints of large mammals ($n = 22$) was thicker than the crust near burrows not made in mammal prints ($n = 524$; 2-tailed t-test; $t = 2.07$, $P < 0.025$). We located 4 arroyo toads burrowed within rodent burrows from June through September.

We observed 12 arroyo toads that made burrows ($n = 20$ burrows) horizontally into small walls of alluvial sand less than 30 cm high. These were formed by erosive action of water through loose sand deposits and were moist within 1 cm of the wall surface. Burrows made in such steep sands were well concealed because sands above would cascade down and cover evidence of digging. We tracked 4 arroyo toads to rodent burrows, and 2 animals burrowed in loose substrates piled next to a rodent burrow.

Selection of Vegetation Types Located at Burrow Sites

Significant differences occurred in the log-ratio (used – available) vegetation type vectors for male ($n = 24$) and female ($n = 9$) arroyo toads (MANOVA; Wilks' $\lambda = 0.476$, $F_{10, 22} = 2.417$, $P < 0.05$), so data were not pooled. Both sexes were observed in a variety of mesic and xeric vegetation types. Most vegetation types were not significantly preferred more or less than other vegetation types, so we do not present preferences as a ranked list (Table 3). Males showed significant preference for agricultural microhabitats compared to all but oak ($d = 1.038$, $P = 0.068$) and coastal sage ($d = 1.219$, $P = 0.102$) microhabitats. Both oak and coastal sage microhabitats, though, were only significantly preferred compared to annual plant microhabitats, so preference ranks are inconclusive. Annual plants were preferred significantly less than all other vegetation types except nonnative grasses ($d = -1.127$, $P = 0.232$) and no vegetation ($d = -1.393$, $P = 0.143$).

Analysis of female arroyo toad vegetation type preference was hampered by the low number of female arroyo toads ($n = 9$) with adequate MCP areas to generate the comparative used and available data. Compositional analysis cannot discriminate preferences among habitat types when the number of habitat types is greater than the number of animals observed. Even after we removed agricultural, exotic, and chaparral vegetation types from the analysis because they were not used by these 9 females during our study, few significant differences occurred in toad preference for vegetation types. Females preferred organic debris piles significantly less than sycamore (d = –3.380, P = 0.018) and oak (d = –2.894, P = 0.020). Sycamore was slightly preferred over nonnative grasses (d = 2. 057, P = 0.074) or no vegetation (d = 2.023, P = 0.078).

Selection of Vegetation Structure Types at Burrow Sites

No significant differences occurred in the log-ratio (used – available) vegetation structure type vectors for male (n = 24) and female (n = 9) arroyo toads (MANOVA; Wilks' $\lambda = 0.810$, $F_{6,26}$ = 1.014, P = 0.438), so data were pooled. The most preferred vegetation structure types were no vegetation, sparse–tall, and medium–tall. No significant difference occurred in preference between these types. There was a slight preference for microhabitats with no vegetation over medium–low vegetation (d = 1.548, P = 0.093). Medium–canopied structure was significantly preferred over all dense structures and slightly more than (d = 1.253, P = 0.066) sparse–low structure. Medium–low, however, was not significantly preferred over sparse–tall, medium–tall, sparse–low, or dense–low. Because of overlapping nonsignificant differences, the preference ranking we present in Table 3 is open to alternate interpretations. Toads seemed to select habitat more according to vegetation structure than vegetation type; dense–tall structures were preferred least of all. At our study site, dense–tall structures were most often associated with tall native and nonnative plants in nonscoured habitats.

Selection of Microhabitats by Active Arroyo Toads

The sample size of arroyo toads with adequately sampled MCP areas and 1 or more observations of surface activity was smaller (n = 21) than for burrowed arroyo toads. Overall microhabitat type use was significantly nonrandom in all 3 analyses of active arroyo toad data according to likelihood ratio tests (P < 0.001), but our data do not allow for a ranking of vegetation type or vegetation structure preferences for active arroyo toads. Data from active arroyo toad locations revealed no differences in preference between clay–silt, gravel, fine, medium, and coarse sand types, although cobble habitats were preferred significantly less than gravel, coarse sand, and fine sand. Active arroyo toads may forage and disperse through many microhabitats found in natural floodplains, but this may be a reflection of low power resulting from a low number of active locations per animal and a low number of active animals in the analysis.

Escapes, Injuries, Ovulation, and the Belt and Transmitter System

Of 83 arroyo toads tracked, 41 escaped from the belt and transmitter system; half of these escaped in <20 days. The belt and transmitter system did not appear to impede arroyo toad movement; all toads seemed to hop normally, and many moved over 500 m. We released 18 toads from the belt and transmitter because we found abraded skin under the belt and transmitter, apparently due to a rough film of silt and sloughed skin that accumulated on the belt. Abrasion most often was a slight chafing but led to open sores on occasion.

Surprisingly, we did not find that the belt interfered with breeding. Five of 16 females tracked during the breeding season moved upstream to breed. Three of these returned downstream after breeding. Transmitters fell off the other 2 females, apparently during amplexus with a male; these transmitters were both recovered next to egg masses. We know of no females that moved downstream to breed, although there were, in all cases, known choruses of calling males both upstream and downstream of the female burrow locations. The belt and transmitter did not prevent these females from moving up to 675 m to a male chorus site, and ovulating.

DISCUSSION

We found arroyo toad habitat preferences at the spatial scale of minimum convex polygon (MCP) home range estimate and microhabitats during the breeding season. The MCP defined by a toad's burrowed and active locations is, by definition, a minimum area circumscribed by each toad's own movements. Not all points within a MCP are physically occupied by the animal, but the habitats within it are termed used for use versus availability comparisons of second-order habitat selection because they reflect the general surroundings at a broad spatial scale that each individual has chosen, out of all habitats present in the study site subarea. At the finer scale of third-order habitat selection, the area within a MCP was by definition available to an animal because it is bounded by points where the animal was observed (Aebischer et al 1993). The designation of these habitats as potentially available is conservative because we have no reliable infor-

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mation about the range of nightly movement distances. We observed strong preferences despite a small number of observations for some animals, which suggests that the preference for these habitats is strong across the arroyo toads in this study.

Arroyo toads appear to be more specific in their microhabitat preferences for burrowing sites than for sites of activity on the surface. Toads use underground burrows as refugia from predation and dessication, so survival may depend on the availability of high-quality burrow habitat. Fine-, medium-, and coarse-grained sands were the clearly preferred substrates for arroyo toad burrows during our observations. Maintaining the widespread availability of suitable burrowing sites in a watershed seems necessary to minimize the risk of mortality.

At the scale of second-order selection, which relied on both burrowed and active locations to delimit MCP, we found highest male preference for habitats in recently scoured flood channels, and highest female preference for both terrace and channel habitats. These results likely reflect behavioral differences during the breeding season. Males were generally in daytime burrows close to the river, from which they moved at night to the river to call for females. Females tended to remain on terraces, then make long upstream moves over the course of 1 or a few nights, breed, then return to terrace habitats. The more vegetated terrace and upland habitats may provide higher quality cover and forage during the breeding season.

Channel and terrace habitats are critical for arroyo toads prior to, during, and after the breeding season. Our observations of arroyo toad movement in upland habitats confirm that human activities in upland habitats, including campgrounds and agricultural fields, also are likely to affect adult survival. There is no season when certain human disturbances in upland habitats near known populations are certain not to harm arroyo toads. Our tracking data probably underestimated the extent to which adult arroyo toads move into terrace and upland habitats after the completion of individual breeding activity because of the limited time scope of our study and because many toads escaped from belts after short periods of observation. The MCP recorded in this study may not include extensive upland habitat used before and after monitoring.

We recorded a significant increase of arroyo toad use of agricultural field habitats after the breeding season. Cunningham (1961) also noted arroyo toad use of irrigated fields. Agricultural fields may be attractive to arroyo toads; substrates were moist along drip-irrigation hoses, there was vegetative cover from crop and non-crop plants, and small invertebrates were abundant. However, agricultural fields may be ecological traps that appear to provide adequate habitat for arroyo toads at some times, but are dangerous for arroyo toads at other times. Mechanized tilling, pesticide application, and trampling were frequent in fields on our study site. To reduce mortality, agriculture-free buffer zones should be established next to known arroyo toad breeding sites. Any buffer zone should be much wider than 134.9 m, which was the mean maximum distance we observed individual females away from breeding streams during the breeding season. Both sexes moved further into upland habitats after the breeding season, so buffer strip width should be determined by future studies conducted in fall and winter.

Sands were clearly the preferred burrowing substrate for both sexes of arroyo toads. In the San Mateo River watershed, sand substrates are provided by natural erosion and alluvial processes and generally are sorted by size through the action of stream flow. In contrast, fine-grained and unsorted soil and silt from grading and road construction do not provide the preferred substrates for arroyo toad burrows. A human-caused overload of silt in a watershed could cover sands with a layer of undesirable burrowing substrates downstream. Steep walls of alluvial sand provide easy access to cool, damp sands with minimal burrowing effort; these habitats may be more important in dry seasons if the expenditure of energy in daily burrowing is a significant energy loss. If this is the case, then degradation of these sand cliffs in the microtopography should be avoided in areas of high toad density. Reaching moist sands through friable surfaces may be even more important for juvenile toads. Active arroyo toads used a wider variety of substrate types than burrowed arroyo toads. Cobble substrates were least preferred for active arroyo toads.

Human activities that can degrade burrow sites and crush animals outright include construction, off-road vehicle use, walking, and livestock grazing. Vehicular and foot traffic in campgrounds can be dangerous for arroyo toads. Human recreation in riparian and river habitats during arroyo toad breeding and larval development periods may be a significant source of direct mortality (U.S. Fish and Wildlife Service 1999).

Our results support prior conclusions that overly scoured river channels and those receiving little input of sediment from upstream are not favorable for arroyo toads (U.S. Fish and Wildlife Service 1999); the proportional number of observed arroyo toad burrows in either cobble or silt and clay substrates was far smaller than the proportional availability of these substrates. We confirmed the suspicion that certain human activities upstream can have substantial negative impacts on terrestrial as well as breeding habitats. Reservoirs, lowering of water tables from irrigation, urban development, and sediment mining all can cause a net loss of the sandy aquatic pool habitats where arroyo toads breed (U.S. Fish and Wildlife Service 1999, Federal Register 2001), and a loss of sand deposits in floodplain habitats that we have shown arroyo toads prefer for burrowing throughout the year.

MANAGEMENT IMPLICATIONS

Despite the extreme specificity of arroyo toads for successful breeding and larval development habitats (U.S. Fish and Wildlife Service 1999), our results suggest that burrowed and active arroyo toads may be found under many vegetation types. We found that arroyo toads preferred dense-canopied vegetation structures the least, regardless of vegetation type.

Of 3 watersheds in USMCB Camp Pendleton with arroyo toads, the San Mateo River watershed may have the largest extant population, with at least 391 individuals recorded in the lower San Mateo subarea between 1996–2000 (D. Holland, Camp Pendleton Amphibian and Reptile Survey, unpublished data). Our work indicates that natural flooding and the continuity of riparian and upland habitats may play roles in maintaining this large population. This conclusion rests on the assumption that the widespread availability of preferred habitats leads to higher survival in some way (Garshelis 2000). An 8-lane freeway that has been proposed for this watershed in the immediate vicinity of breeding and upland habitats could impact arroyo toads through an influx of unsorted sediments into the stream channels during construction, a disruption of normal hydrological patterns and sediment transport in the watershed, and the creation of a barrier between upland and floodplain habitats. Previous work also points to heavy deposits of alluvial silt and clay as potentially fatal hazards for arroyo toad larvae (U.S. Fish and Wildlife Service 1999).

Our results suggest, in general, that large influxes of fine and unsorted sediment, or changes to the sediment deposition regime in a watershed, could reduce the amount of preferred burrowing habitats in the immediate vicinity of a construction site, and in the downstream area of the floodplain. Freeways and other urban developments create large areas of impervious substrates in a watershed, which can increase flood intensity, leading eventually to a lower availability of sands in the floodplain.

We found no evidence contrary to previous work identifying risks to arroyo toad populations (U.S. Fish and Wildlife Service 1999). Through our tracking studies, we found that agricultural fields may be dangerous for arroyo toads. Agricultural fields contain preferred burrowing conditions for arroyo toads but can be periodically disturbed by trampling, chemicals, and machinery.

Until studies have covered the range of variation in climatic and habitat conditions that arroyo toad populations may experience, no conclusions about minimum amounts of critical habitat should be made. Very little is known about arroyo toads outside the breeding season; our results come only from the spring and summer seasons. For a more complete understanding of arroyo toad habitat needs, additional studies should identify patterns of habitat use in fall and winter. Toad movements observed during only the breeding season or during only a wet year most likely will fail to document the extent and types of habitats that are necessary to maintain viable arroyo toad populations during dry years and nonbreeding seasons, such as refugia used during droughts. We observed that arroyo toads repeatedly navigated to specific burrows from over 200 m away, so it is conceivable that individual arroyo toads would return to specific locales where survival is high under environmentally stressful conditions. It will be especially important to determine whether arroyo toads rely on certain upland habitats, riparian habitats, seeps, or springs for survival through drought periods. Our research confirms that floodplain landforms (channels and terraces) and sand substrates are important features for arroyo toads during the breeding season. We also have confirmed that dense stands of tall vegetation are not preferred burrowing habitats. To understand the range of conditions that may influence habitat use and selection in this species, future studies will need to determine habitat preferences during the fall and winter and during dry years without El Niño rainfall. Other studies should assess

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MICROHABITAT S
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Abstract: The Texas horned
tat selection by the Texas ho
al habitat requirements of
management treatments in s
ment. Adult lizards caught in
Habitat characteristics at rad
quadrats. Relocations were
inactive). Horned lizards us
and evening for thermoregu
noons, lizards selected woo
appeared less dependent on
tive season compared to the
habitat selection among lar
focus on creating a mosaic c

Key words: burning, grazing

The Texas horned lizar
States throughout Texas
as parts of Kansas, Miss
zona, and Mexico (Mung
has declined throughout
Habitat destruction, in
imported fire ant (*Solenc*
insecticides are putative
(Price 1990, Donaldson e

Habitat use by Texas h
studied in the past (Whit
and Carter 1994; Fair a
However, these studies of
tion on specific habitat r
tion. For example, Fair
pled habitat selection c
lizards, but did not consi
management practices
study site had on that se
(1993) studied habitat se
horned lizards were most

Texas horned lizards r
including open deserts
with sparse vegetation
1990, Whiting et al. 199

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